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The Influence of Pulse Radiation Processing on The Properties of Materials

Evgeny L. Pankratov*

Nizhny Novgorod State Agrotechnical University, 97 Gagarin Avenue, Nizhny Novgorod, 603950, Russia; elp2004@mail.ru.

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Abstract

In this paper, we consider the influence of pulse radiation processing on the properties of materials. In pulse radiation processing, we consider periodically repeated processing of materials by radiation particles with fixed continuance and dose, as well as frequency and energy of processing of materials by required particles. We show that the existing specific frequency and duration of pulses. An increase in the frequency of pulses of radiation processing in comparison with the particular frequency leads to the accumulation of radiation defects. Also, we introduce an analytical approach for the analysis of the transport of radiation defects and their interaction with each other.

Keywords: Radiation defects, Pulse radiation processing, Analytical approach for analysis.

1 | Introduction

One of the actual points of solid state electronics is increasing the radiation resistance of appropriate devices. To improve the radiation resistance of solid-state electronic devices, different approaches [1]–[5] have been developed. In this paper, we consider the influence of pulse radiation processing on the properties of materials for solid-state electronic devices. In pulse radiation processing, we consider periodically repeated processing of materials by radiation particles with fixed continuance and dose, as well as frequency and energy of processing of materials by required particles. The main aim of the present paper is the analysis of the influence of the frequency and continuance of the pulse of radiation processing on radiation materials. Another aim of the present paper is the development of an analytical approach for the analysis of the transport of radiation defects and their interaction with each other, with account for changes of their parameters in space and time, as well as the nonlinearity of the considered transport.

Corresponding Author: elp2004@mail.ru

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2 | Method of Solution

Distributions of concentrations of point radiation defects in space and time were determined by solution of the following system of equations [6], [7].

$$\frac{\partial I(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_I(x,y,z,T)\frac{\partial I(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_I(x,y,z,T)\frac{\partial I(x,y,z,t)}{\partial y}\right]+$$

$$\frac{\partial}{\partial z}\left[D_I(x,y,z,T)\frac{\partial I(x,y,z,t)}{\partial z}\right]-k_{I,V}(x,y,z,T)I(x,y,z,t)V(x,y,z,t)- \quad \textbf{(1)}$$

$$k_{I,I}(x,y,z,T)I^2(x,y,z,t).$$

$$\frac{\partial V(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_V(x,y,z,T)\frac{\partial V(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_V(x,y,z,T)\frac{\partial V(x,y,z,t)}{\partial y}\right]+$$

$$\frac{\partial}{\partial z}\left[D_V(x,y,z,T)\frac{\partial V(x,y,z,t)}{\partial z}\right]-k_{I,V}(x,y,z,T)I(x,y,z,t)V(x,y,z,t)-$$

$$k_{V,V}(x,y,z,T)V^2(x,y,z,t).$$

With the following boundary and initial conditions

$$\left.\frac{\partial \rho(x,y,z,t)}{\partial x}\right|_{x=0}=0,\ \left.\frac{\partial \rho(x,y,z,t)}{\partial x}\right|_{x=L_x}=0,\ \left.\frac{\partial \rho(x,y,z,t)}{\partial y}\right|_{y=0}=0,$$

$$\left.\frac{\partial \rho(x,y,z,t)}{\partial y}\right|_{y=L_y}=0,\ \left.\frac{\partial \rho(x,y,z,t)}{\partial z}\right|_{z=0}=0,\ \left.\frac{\partial \rho(x,y,z,t)}{\partial z}\right|_{z=L_z}=0,\ \rho\ (x,y,z,0)=f_\rho\ (x,y,z). \quad \textbf{(2)}$$

Here ρ describes type of point radiation defects (I or V); function I (x,y,z,t) describes distribution of radiation interstitials in space and time; function V (x,y,z,t) describes distribution of radiation vacancies in space and time; D_ρ (x,y,z,T) is the diffusion coefficients of radiation interstitials and vacancies; terms V^2 (x,y,z,t) and I^2 (x,y,z,t) correspond to generation of divacancies and diinterstitials; $k_{I,V}$ (x,y,z,T) is the parameter of recombination of point radiation defects; $k_{\rho,\rho}$ (x,y,z,T) are the parameters of generation of simplest complexes of point radiation defects.

We determine spatio-temporal distributions of concentrations of divacancies Φ_V (x, y,z,t) and diinterstitials Φ_I (x,y,z,t) by solving the following system of equations [6], [7].

$$\frac{\partial \Phi_I(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_{\Phi_I}(x,y,z,T)\frac{\partial \Phi_I(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_{\Phi_I}(x,y,z,T)\frac{\partial \Phi_I(x,y,z,t)}{\partial y}\right]+$$

$$\frac{\partial}{\partial z}\left[D_{\Phi_I}(x,y,z,T)\frac{\partial \Phi_I(x,y,z,t)}{\partial z}\right]+k_{I,I}(x,y,z,T)I^2(x,y,z,t)-k_I(x,y,z,T)I(x,y,z,t). \quad \textbf{(3)}$$

$$\frac{\partial \Phi_V(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_{\Phi_V}(x,y,z,T)\frac{\partial \Phi_V(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_{\Phi_V}(x,y,z,T)\frac{\partial \Phi_V(x,y,z,t)}{\partial y}\right]$$

$$+\frac{\partial}{\partial z}\left[D_{\Phi_V}(x,y,z,T)\frac{\partial \Phi_V(x,y,z,t)}{\partial z}\right]+k_{V,V}(x,y,z,T)V^2(x,y,z,t)-k_V(x,y,z,T)V(x,y,z,t).$$

With boundary and initial conditions

$$\left.\frac{\partial \Phi_\rho(x,y,z,t)}{\partial x}\right|_{x=0}=0,\ \left.\frac{\partial \Phi_\rho(x,y,z,t)}{\partial x}\right|_{x=L_x}=0,\ \left.\frac{\partial \Phi_\rho(x,y,z,t)}{\partial y}\right|_{y=0}=0,$$

$$\left.\frac{\partial \Phi_\rho(x,y,z,t)}{\partial y}\right|_{y=L_y}=0,\ \left.\frac{\partial \Phi_\rho(x,y,z,t)}{\partial z}\right|_{z=0}=0,\ \left.\frac{\partial \Phi_\rho(x,y,z,t)}{\partial z}\right|_{z=L_z}=0, \tag{4}$$

$\Phi_I(x,y,z,0)=f_{\Phi I}(x,y,z)$, $\Phi_V(x,y,z,0)=f_{\Phi V}(x,y,z)$.

Here, $D_{\Phi\rho}(x,y,z,T)$ are the diffusion coefficients of complexes of radiation defects; $k_\rho(x,y,z,T)$ are the parameters of decay of complexes of radiation defects.

We determine spatio-temporal distributions of concentrations of dopant and radiation defects by using the method of averaging of function corrections [8] with decreased quantity of iteration steps. In the framework of the approach, we used solutions of *Eq. (1)* and *Eq. (3)* in linear form and with averaged values of diffusion coefficients D_{0I}, D_{0V}, $D_{0\Phi I}$, $D_{0\Phi V}$ as initial-order approximations of the required concentrations. The solutions could be written as

$$I_1(x,y,z,t)=\frac{F_{0I}}{L_xL_yL_z}+\frac{2}{L_xL_yL_z}\sum_{n=1}^{\infty}F_{nI}c_n(x)c_n(y)c_n(z)e_{nI}(t).$$

$$V_1(x,y,z,t)=\frac{F_{0V}}{L_xL_yL_z}+\frac{2}{L_xL_yL_z}\sum_{n=1}^{\infty}F_{nC}c_n(x)c_n(y)c_n(z)e_{nV}(t).$$

$$\Phi_{I1}(x,y,z,t)=\frac{F_{0\Phi_I}}{L_xL_yL_z}+\frac{2}{L_xL_yL_z}\sum_{n=1}^{\infty}F_{n\Phi_I}c_n(x)c_n(y)c_n(z)e_{n\Phi_I}(t). \tag{5}$$

$$\Phi_{V1}(x,y,z,t)=\frac{F_{0\Phi_V}}{L_xL_yL_z}+\frac{2}{L_xL_yL_z}\sum_{n=1}^{\infty}F_{n\Phi_V}c_n(x)c_n(y)c_n(z)e_{n\Phi_V}(t).$$

Where $e_{n\rho}(t)=\exp\left[-\pi^2n^2D_{0\rho}t\left(\frac{1}{L_x^2}+\frac{1}{L_y^2}+\frac{1}{L_z^2}\right)\right]$, $F_{n\rho}=\int_0^{L_x}c_n(u)\int_0^{L_y}c_n(v)\int_0^{L_z}c_n(v)f_\rho(u,v,w)\,dw\,dv\,du$, $c_n(\chi)=\cos(\pi n\,\chi/L_\chi)$.

The second-order approximations and approximations with higher orders of concentrations of dopant and radiation defects were determined in the framework of a standard iterative procedure. In the framework of the procedure to calculate approximations with the n-order one shall replace the functions $I(x,y,z,t)$, $V(x,y,z,t)$, $\Phi_I(x, y,z,t)$, $\Phi_V(x,y,z,t)$ in the right sides of the *Eq. (1)* and *Eq. (3)* on the following sums $\alpha_{n\rho}+\rho_{n-1}(x,y,z,t)$. As an example, we present equations for the second-order approximations of the considered concentrations.

$$\frac{\partial I_2(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_I(x,y,z,T)\frac{\partial I_1(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_I(x,y,z,T)\frac{\partial I_1(x,y,z,t)}{\partial y}\right]+$$

$$\frac{\partial}{\partial z}\left[D_I(x,y,z,T)\frac{\partial I_1(x,y,z,t)}{\partial z}\right]-k_{I,V}(x,y,z,T)\left[\alpha_{2I}+I_1(x,y,z,t)\right]\left[\alpha_{2V}+V_1(x,y,z,t)\right]- \quad \textbf{(6)}$$

$$k_{I,I}(x,y,z,T)\left[\alpha_{2I}+I_1(x,y,z,t)\right]^2.$$

$$\frac{\partial V_2(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_V(x,y,z,T)\frac{\partial V_1(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_V(x,y,z,T)\frac{\partial V_1(x,y,z,t)}{\partial y}\right]+$$

$$\frac{\partial}{\partial z}\left[D_V(x,y,z,T)\frac{\partial V_1(x,y,z,t)}{\partial z}\right]-k_{I,V}(x,y,z,T)\left[\alpha_{2I}+I_1(x,y,z,t)\right]\left[\alpha_{2V}+V_1(x,y,z,t)\right]-$$

$$k_{V,V}(x,y,z,T)\left[\alpha_{2V}+V_1(x,y,z,t)\right]^2.$$

$$\frac{\partial \Phi_{I2}(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_{\Phi_I}(x,y,z,T)\frac{\partial \Phi_{I1}(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_{\Phi_I}(x,y,z,T)\frac{\partial \Phi_{I1}(x,y,z,t)}{\partial y}\right]$$

$$+\frac{\partial}{\partial z}\left[D_{\Phi_I}(x,y,z,T)\frac{\partial \Phi_{I1}(x,y,z,t)}{\partial z}\right]+k_{I,I}(x,y,z,T)I^2(x,y,z,t)-k_I(x,y,z,T)I(x,y,z,t).$$

$$\frac{\partial \Phi_{V2}(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_{\Phi_V}(x,y,z,T)\frac{\partial \Phi_{V1}(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_{\Phi_V}(x,y,z,T)\frac{\partial \Phi_{V1}(x,y,z,t)}{\partial y}\right] \quad \textbf{(7)}$$

$$+\frac{\partial}{\partial z}\left[D_{\Phi_V}(x,y,z,T)\frac{\partial \Phi_{V1}(x,y,z,t)}{\partial z}\right]+k_{V,V}(x,y,z,T)V^2(x,y,z,t)-k_V(x,y,z,T)V(x,y,z,t).$$

Integration of the left and right sides of *Eq. (6)* and *Eq. (7)* gives us the possibility to obtain relations for the second-order approximations of concentrations of radiation defects in the following final form.

$$I_2(x,y,z,t)=\frac{\partial}{\partial x}\left[\int_0^t D_I(x,y,z,T)\frac{\partial I_1(x,y,z,\tau)}{\partial x}d\tau\right]+\frac{\partial}{\partial y}\left[\int_0^t D_I(x,y,z,T)\times\right.$$

$$\left.\frac{\partial I_1(x,y,z,\tau)}{\partial y}d\tau\right]+\frac{\partial}{\partial z}\left[\int_0^t D_I(x,y,z,T)\frac{\partial I_1(x,y,z,\tau)}{\partial z}d\tau\right]-\int_0^t k_{I,I}(x,y,z,T)\times \quad \textbf{(6a)}$$

$$\left[\alpha_{2I}+I_1(x,y,z,\tau)\right]^2 d\tau+f_I(x,y,z)-\int_0^t k_{I,V}(x,y,z,T)\left[\alpha_{2I}+I_1(x,y,z,\tau)\right]\times$$

$$\left[\alpha_{2V}+V_1(x,y,z,\tau)\right]d\tau.$$

$$V_2(x,y,z,t)=\frac{\partial}{\partial x}\left[\int_0^t D_V(x,y,z,T)\frac{\partial V_1(x,y,z,\tau)}{\partial x}d\tau\right]+\frac{\partial}{\partial y}\left[\int_0^t D_V(x,y,z,T)\times\right.$$

$$\left.\frac{\partial V_1(x,y,z,\tau)}{\partial y}d\tau\right]+\frac{\partial}{\partial z}\left[\int_0^t D_V(x,y,z,T)\frac{\partial V_1(x,y,z,\tau)}{\partial z}d\tau\right]-\int_0^t k_{V,V}(x,y,z,T)\times$$

$$\left[\alpha_{2I}+V_1(x,y,z,\tau)\right]^2 d\tau+f_V(x,y,z)-\int_0^t k_{I,V}(x,y,z,T)\left[\alpha_{2I}+I_1(x,y,z,\tau)\right]\times$$

$$\left[\alpha_{2V}+V_1(x,y,z,\tau)\right]d\tau.$$

$$\Phi_{I2}(x,y,z,t)=\frac{\partial}{\partial x}\left[\int_0^t D_{\Phi_I}(x,y,z,T)\frac{\partial \Phi_{I1}(x,y,z,\tau)}{\partial x}d\tau\right]+\frac{\partial}{\partial y}\left[\int_0^t D_{\Phi_I}(x,y,z,T)\times\right.$$

$$\left.\frac{\partial \Phi_{I1}(x,y,z,\tau)}{\partial y}d\tau\right]+\frac{\partial}{\partial z}\left[\int_0^t D_{\Phi_I}(x,y,z,T)\frac{\partial \Phi_{I1}(x,y,z,\tau)}{\partial z}d\tau\right]+\int_0^t k_{I,I}(x,y,z,T)\times \qquad \textbf{(7a)}$$

$$I^2(x,y,z,\tau)d\tau-\int_0^t k_I(x,y,z,T)I(x,y,z,\tau)d\tau+f_{\Phi_I}(x,y,z).$$

$$\Phi_{V2}(x,y,z,t)=\frac{\partial}{\partial x}\left[\int_0^t D_{\Phi_V}(x,y,z,T)\frac{\partial \Phi_{V1}(x,y,z,\tau)}{\partial x}d\tau\right]+\frac{\partial}{\partial y}\left[\int_0^t D_{\Phi_V}(x,y,z,T)\times\right.$$

$$\left.\frac{\partial \Phi_{I1}(x,y,z,\tau)}{\partial y}d\tau\right]+\frac{\partial}{\partial z}\left[\int_0^t D_{\Phi_V}(x,y,z,T)\frac{\partial \Phi_{V1}(x,y,z,\tau)}{\partial z}d\tau\right]+\int_0^t k_{V,V}(x,y,z,T)\times$$

$$V^2(x,y,z,\tau)d\tau-\int_0^t k_V(x,y,z,T)V(x,y,z,\tau)d\tau+f_{\Phi_V}(x,y,z).$$

We determine average values of the second-order approximations of the considered concentrations by using the following standard relations

$$\alpha_{2\rho}=\frac{1}{\Theta L_x L_y L_z}\int_0^{\Theta}\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}\left[\rho_2(x,y,z,t)-\rho_1(x,y,z,t)\right]dz\,dy\,dx\,dt. \qquad \textbf{(8)}$$

Substitution of *Relations (6a)* and *(7a)* into *Relation (8)* gives us the possibility to obtain relations for the required average values $\alpha_{2\rho}$

$$\alpha_{2I} = \frac{1}{2A_{II00}}\left\{\left(1 + A_{IV01} + A_{II10} + \alpha_{2V}A_{IV00}\right)^2 - 4A_{II00}\left[\alpha_{2V}A_{IV10} - A_{II20} + A_{IV11} - \right.\right.$$

$$\left.\left.\frac{1}{L_xL_yL_z}\int_0^{L_x}\int_0^{L_y}\int_0^{L_z} f_I(x,y,z)\,dz\,dy\,dx\right]\right\}^{\frac{1}{2}} - \frac{1 + A_{IV01} + A_{II10} + \alpha_{2V}A_{IV00}}{2A_{II00}}. \quad (9)$$

$$\alpha_{2V} = \frac{1}{2B_4}\sqrt{\frac{\left(B_3 + A\right)^2}{4} - 4B_4\left(y + \frac{B_3 y - B_1}{A}\right)} - \frac{B_3 + A}{4B_4}, \quad (10)$$

where $A_{abij} = \frac{1}{\Theta L_xL_yL_z}\int_0^{\Theta}(\Theta - t)\int_0^{L_x}\int_0^{L_y}\int_0^{L_z} k_{a,b}(x,y,z,T)\,I_1^i(x,y,z,t)\,V_1^j(x,y,z,t)\,dz\,dy\,dx\,dt.$

$$B_4 = A_{IV00}^2A_{IV00}^2 - 2\left(A_{IV00}^2 - A_{II00}A_{VV00}\right)^2,\ B_3 = A_{IV00}A_{IV00}^2 + A_{IV01}A_{IV00}^3 + A_{IV00}A_{II10}A_{IV00}^2 -$$

$$4\left(A_{IV00}^2 - A_{II00}A_{VV00}\right)\left[2A_{IV01}A_{IV00} + 2A_{IV00}\left(1 + A_{IV01} + A_{II10}\right) - 2A_{II00}\left(A_{IV10} + A_{VV10} + 1\right)\right] -$$

$$4A_{IV10}A_{II00}A_{IV00}^2 + 2A_{IV00}A_{IV01}A_{IV00}^2,\ B_2 = A_{IV00}^2\left\{\left(1 + A_{IV01} + A_{II10}\right)^2 + A_{IV00}^2A_{IV01}^2 + A_{IV00}\times\right.$$

$$2A_{IV00}\left(A_{IV00} + A_{IV00}A_{IV01} + A_{IV00}A_{II10} - 4A_{IV10}A_{II00}\right) - 4A_{II00}\left[A_{IV11} - A_{II20} - \frac{1}{L_xL_yL_z}\times\right.$$

$$\left.\left.\int_0^{L_x}\int_0^{L_y}\int_0^{L_z} f_I(x,y,z)\,dz\,dy\,dx\right]\right\}\left\{\left[2A_{IV01}A_{IV00} + 2A_{IV00}\left(1 + A_{IV01} + A_{II10}\right) - 2A_{II00}\left(A_{IV10} + 1 + \right.\right.\right.$$

$$\left.\left.A_{VV10}\right)\right]^2 + 2\left[A_{IV01}\left(1 + A_{IV01} + A_{II10}\right) + \frac{2}{L_xL_yL_z}\int_0^{L_x}\int_0^{L_y}\int_0^{L_z} f_V(x,y,z)\,dz\,dy\,dx - 2A_{II00}\left(A_{VV20} - \right.\right.$$

$$\left.\left.A_{IV11}\right) + A_{IV01}\left(1 + A_{IV01} + A_{II10}\right)\right]\left[2A_{IV00}\left(1 + A_{IV01} + A_{II10}\right) + 2A_{IV01}A_{IV00} - 2A_{II00}\left(A_{IV10} + 1 + \right.\right.$$

$$\left.\left.\left.A_{VV10}\right)\right]\right\},\ B_1 = 2A_{IV00}A_{IV01}\left(1 + A_{IV01} + A_{II10}\right)^2 - 8\left[A_{IV11} - \frac{1}{L_x}\int_0^{L_x}\int_0^{L_y}\int_0^{L_z} f_I(x,y,z)\,dz\,dy\,dx\times\right.$$

$$\left.\frac{1}{L_yL_z} - A_{II20}\right] + A_{IV00}A_{IV01}A_{II00} + A_{IV01}^2\left(A_{IV00} + A_{IV00}A_{IV01} + A_{IV00}A_{II10} - 4A_{IV10}A_{II00}\right) -$$

$$2\left[\frac{2A_{II00}}{L_xL_yL_z}\int_0^{L_x}\int_0^{L_y}\int_0^{L_z} f_I(x,y,z)\,dz\,dy\,dx + A_{IV01}\left(1 + A_{IV01} + A_{II10}\right) - 2A_{II00}\left(A_{VV20} - A_{IV11}\right) + \right.$$

$$A_{IV01}\left(1+A_{IV01}+A_{II10}\right)\Big]\Big[2A_{IV00}\left(1+A_{IV01}+A_{II10}\right)-2\left(A_{IV10}+A_{VV10}+1\right)A_{II00}+2A_{IV01}A_{IV00}\Big],$$

$$B_0=4A_{II00}A_{IV01}^2\left[A_{II20}+\frac{1}{L_xL_yL_z}\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}f_I\left(x,y,z\right)dz\,dy\,dx-A_{IV11}\right]+A_{IV01}^2\left(A_{IV01}+A_{II10}+\right.$$

$$\left.1\right)^2-\left[\frac{2A_{II00}}{L_xL_yL_z}\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}f_V\left(x,y,z\right)dz\,dy\,dx+A_{IV01}\left(1+A_{IV01}+A_{II10}\right)-2A_{II00}\left(A_{VV20}-A_{IV11}\right)+\right.$$

$$\left.A_{IV01}\left(1+A_{IV01}+A_{II10}\right)\right]^2,\ y=\sqrt[3]{\sqrt{q^2+p^3}-q}-\sqrt[3]{\sqrt{q^2+p^3}+q}+\frac{B_2}{6},\ q=\left(2B_1B_3-8B_0\right)\times$$

$$\frac{B_2}{48}+\frac{B_2^3}{216}+\frac{B_0\left(4B_2-B_3^2\right)-B_1^2}{8},\ p=\left[3\left(2B_1B_3-8B_0\right)-2B_2^2\right]/72,\ A=\sqrt{8y+B_3^2-4B_2},$$

$$\alpha_{2\Phi_I}=A_{II20}-\frac{1}{\Theta L_xL_yL_z}\int_0^{\Theta}\left(\Theta-t\right)\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}k_I\left(x,y,z,T\right)I\left(x,y,z,t\right)dz\,dy\,dx\,dt+$$
$$\frac{1}{L_xL_yL_z}\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}f_{\Phi I}\left(x,y,z\right)dz\,dy\,dx. \tag{11}$$

$$\alpha_{2\Phi_V}=A_{VV20}-\frac{1}{\Theta L_xL_yL_z}\int_0^{\Theta}\left(\Theta-t\right)\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}k_V\left(x,y,z,T\right)V\left(x,y,z,t\right)dz\,dy\,dx\,dt+$$
$$\frac{1}{L_xL_yL_z}\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}f_{\Phi V}\left(x,y,z\right)dz\,dy\,dx. \tag{12}$$

Analysis of spatio-temporal distributions of concentrations of radiation defects has been done by using their second-order approximations in the framework of the method of averaging function corrections with a decreased quantity of iterative steps. The second-order approximation is usually a good enough approximation to make qualitative analysis and obtain some quantitative results. Results of the analytical calculation have been checked by comparison with the results of the numerical simulation.

3 | Discussion

In this section, we analyzed distributions of concentrations of radiation defects in the considered material. *Fig. 1* shows the dependence of the above concentration on the frequency of radiation processing of homogeneous material. The period T_0 corresponding to the frequency ω_0 is approximately equal to $T_0 \approx L^2/6D_0$. The period coincides with the relaxation time of the concentration of radiation defects. In this situation, during a larger T_0, one can obtain a stationary distribution of radiation defects. Over time, with a smaller T_0, one can obtain an accumulation of radiation defects. Changing the parameters of mass transport in space and time leads to a change in the value of frequency ω_0. Dependence of concentration of radiation defects on the continuance of pulse of radiation processing qualitatively coincides with the dependence from *Fig. 1*.

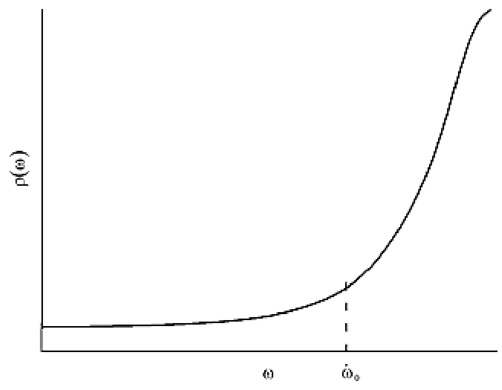

Fig. 1. Typical dependence of concentration of radiation defects on frequency of radiation processing of homogeneous material.

4 | Conclusion

The paper presents the results of an analysis of the influence of pulse radiation processing of materials. The study shows existing specific frequency ω_0 and continuance of pulses τ_0. Increasing the frequency over ω_0 leads to the accumulation of radiation defects. Also, we introduce an analytical approach for the analysis of the transport of radiation defects and their interaction with each other.

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